

## **2 Description of Sudbury Reservoir Watershed Resources**

### **2.1 Watershed Description**

The Sudbury Reservoir System watershed is 8.8% of the greater Sudbury-Assabet-Concord (SuAsCo) drainage basin in Massachusetts. The OWM/MWRA drinking water supply system includes 4.3 square miles within two sub-basins that comprise the Sudbury Reservoir System watersheds. These sub-basins are divided geographically and referred to as the North and South Basins of Sudbury System. The current system consists of four supply reservoirs: the Sudbury Reservoir, and the Stearns, Brackett, and Foss Reservoirs (also known respectively as Framingham Reservoirs Nos. 1, 2, and 3). The system also contains five aqueducts: the Sudbury, Weston, Wachusett, and Hultman Aqueducts, and the new MetroWest Tunnel. Both the North and South Basins drain into Stearns Reservoir. Releases from Stearns flow into the Sudbury River at the Winter Street Dam and continue east towards the Assabet and Concord Rivers.

#### **2.1.1 North Basin**

The North Basin of the Sudbury Reservoir watershed is contained within five municipalities: Framingham, Marlborough, Southborough, Westborough, and Northborough. Water flows from Stony Brook through the North Basin in a west to east direction.

The North Basin area contains two reservoirs, the Sudbury Reservoir and Foss Reservoir (Framingham Reservoir No. 3). Four aqueducts, the Wachusett, Hultman and Weston Aqueducts and the MetroWest Tunnel, are also contained within the North Basin. The Wachusett Aqueduct delivers water to the Sudbury Reservoir directly from the Wachusett Reservoir. The Wachusett Aqueduct connects the Wachusett and Sudbury Reservoirs at Shaft C, which is located in Marlborough and is part of the north Sudbury basin. Water from the Wachusett Aqueduct flows directly into the Sudbury Reservoir through the Wachusett Open Channel. This is currently the only active supply of drinking water within the entire Sudbury system. Water from Sudbury's North Basin can be used for a DEP declared emergency if the water is boiled prior to consumption. The Sudbury System was last used as an emergency supply in 1981 during a temporary shutdown of City Tunnel for repair work.

The Wachusett Open Channel, from the terminal chamber to Deerfoot Road, is under the jurisdiction of the MWRA. The Authority prohibits public access to the Wachusett Open Channel and all aqueducts. Several easements exist that allow residents to draw water directly from the Wachusett Open Channel, but most of these were written in the early 1900s. There is an ongoing review of these easements underway to determine their current status.

Headwaters for the Sudbury's North Basin lie in Crane's Swamp, which is located in Northborough and Westborough. The Wachusett Aqueduct terminates at Shaft C, located in Crane's Swamp, and water in the aqueduct flows eastward through the Wachusett Open Channel, which is the main tributary of the Sudbury Reservoir. Water from the reservoir is released at the Sudbury Dam and flows into the Stony Brook open channel. The Stony Brook Channel fills Foss Reservoir (Framingham Reservoir No. 3) and then drains into Stearns Reservoir (Framingham Reservoir No. 1), where it is released into the Sudbury River and flows northward.

### **2.1.2 South Basin**

The South Basin is located within six municipalities: Framingham, Ashland, Marlborough, Westborough, Southborough and Hopkinton. The South Basin area contains one aqueduct, the Sudbury Aqueduct, and two reservoirs: Brackett and Stearns Reservoirs (Framingham Reservoirs No. 1 and No. 2). OWM lands also include a portion of the Sudbury River and Cedar Swamp. Headwaters for the Sudbury River originate in brooks in the towns of Upton and Westborough and empty into Cedar Swamp. Water from Cedar Swamp flows easterly into the Sudbury River and drains into Brackett Reservoir at the Sudbury River Dam. Water from Brackett Reservoir flows north and is released into Stearns Reservoir at the Brackett Reservoir Dam. The South Basin also includes the Ashland, Hopkinton and Whitehall Reservoirs. These reservoirs were built as part of the drinking water system. However, as adequate drinking water quality could not be maintained, they were transferred in 1948 to another state agency and are now managed as State Parks by the DCR Division of State Parks and Recreation.

Since the late 1960s, the Sudbury North Basin system has primarily been used as a conduit to convey water from the Wachusett and Quabbin reservoirs to supply distribution reservoirs located within the Boston Metropolitan area. The Sudbury South Basin has not been used for water supply since 1930. In the 1970s, mercury from the Nyanza textile plant was found to have settled in the sediments in the Stearns and Brackett Reservoirs, and led to a Superfund designation for the plant site in 1982. While the EPA-administered clean-up has resulted in significant improvements, Sudbury's South Basin remains unusable for public water supply.

## **2.2 Sudbury Watershed Ownership and Land Use**

The Sudbury Reservoir watershed (including the Sudbury Reservoir and Foss Reservoir (Framingham No. 3) and their drainage areas), referred to in this plan as the North Basin, includes approximately 17,782 acres. 37.5% of this area is in forest cover (on both public and private holdings), 1.2% is in wetland, and 8.2% is open water. Including land and water, OWM controls approximately 22% of the North Basin. 7.2% or 1,275 acres of the remaining watershed are maintained primarily in undeveloped forest cover by the DCR Division of State Parks and Recreation or private conservation organizations (e.g., Sudbury Valley Trustees). Approximately 28% is in developed residential areas, 9% is in industrial/commercial development, and 6% is in agriculture. Future development may cause significant changes to land use as 47% and 20% of the watershed is zoned residential and commercial/industrial respectively (MWRA/MDC, 1997).

The upper Sudbury River watershed includes Brackett Reservoir (Framingham Reservoir No.1) and Stearns Reservoir (Framingham Reservoir No.2) and their watersheds, collectively referred to in this plan as the South Basin. The South Basin includes approximately 30,058 acres. OWM has care and control of 1,078 acres, or about 4% (288 acres is the reservoirs and 790 is OWM land). As these lands are not part of the emergency back-up water supply, OWM has offered to surplus much of this land for conservation purposes to local towns and the MA Division of Fisheries and Wildlife. For this reason, this basin is not a primary focus of this plan. 16.2% or 4,872 acres of the remaining 96% of the watershed over which OWM does not have care and control are currently maintained in undeveloped open space by the MA Division of Fisheries and Wildlife or private organizations (Table 1).

From a water supply viewpoint, the land use pattern in the North Basin is of great concern, with a significant percentage of the land currently developed or in uses that compromise water quality protection. Although the OWM ownership is small, it is located around the reservoir and some of the main tributaries and represents an important buffer to the reservoir. OWM controls approximately 32% of the land within 400 feet of the reservoir and its tributaries. The management of these lands is an important part of the protection of the Sudbury Reservoir.

TABLE 1: SUDBURY RESERVOIR WATERSHED SYSTEM FACTS AND FIGURES

Table 1A: Reservoir Information

Attribute	NORTH BASIN		SOUTH BASIN	
	Sudbury Reservoir	Foss Reservoir (Framingham No.3)	Brackett Reservoir (Framingham No.2)	Stearns Reservoir (Framingham No.1)
Year Built	1896	1878	1878	1878
Volume Capacity	7.254 billion gallons	1.074 billion gallons	562.6 million gallons	311 million gallons
Surface Area	1,292 acres	250 acres	134 acres	154 acres
Watershed Area	22.3 mi <sup>2</sup>	27.6 mi <sup>2</sup>	45.1 mi <sup>2</sup>	74.66 mi <sup>2</sup>
Length of Dam	2000'	1,640'	1,340'	758.8'
Maximum Depth	65'	24'	20'	16'

Information from OWM records

Table 1-B: Land Cover and Land Use Data

Land Cover and Land Use in the Sudbury System Watersheds (includes reservoirs)														
Watershed	Forest		Wetland		Agriculture		Residential		Commercial/ Industrial		Open Water		Other	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
North Basin	6,669	37.5%	221	1.2%	998	5.6%	4,983	28.0%	1,568	8.8%	1,467	8.2%	1,876	10.5%
South Basin	15,220	50.6%	662	2.2%	1,330	4.4%	8,115	27.0%	1,334	4.4%	1,296	4.3%	2,101	7.0%
Total Sudbury System	21,889	45.6%	883	1.8%	2,328	4.8%	13,098	27.4%	2,902	6.1%	2,763	5.8%	3,977	8.3%

Information derived from MassGIS data

Table 1-C: Open Space Ownership

Open Space Ownership in Sudbury System Watershed (area in acres)									
Watershed	Total Acres	DCR/DWSP/OWM Protected				Other Protected		Total Protected	
		Land	Water	Total	%	Acres	%	Acres	%
North Basin	17,782	2,323	1,542	3,865	21.7%	1,275	7.2%	5,140	28.9%
South Basin	30,058	790	288	1,078	3.6%	4,872	16.2%	5,950	19.8%
Total Sudbury System	47,840	3,113	1,830	4,943	10.3%	6,147	12.8%	11,091	23.1%

Information derived from MassGIS data

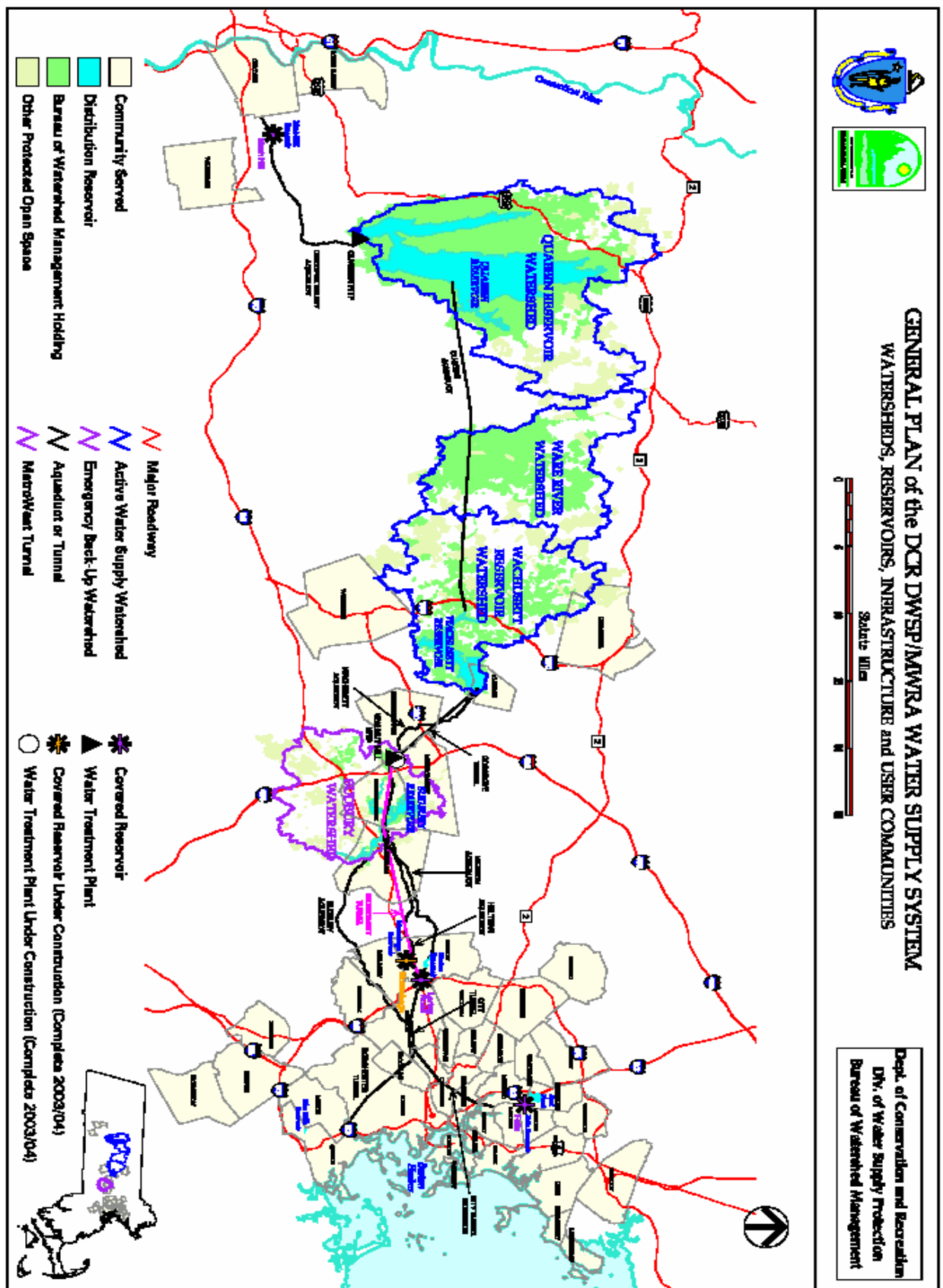


Figure 1: DWSP/OWM - MWRA Water Supply System

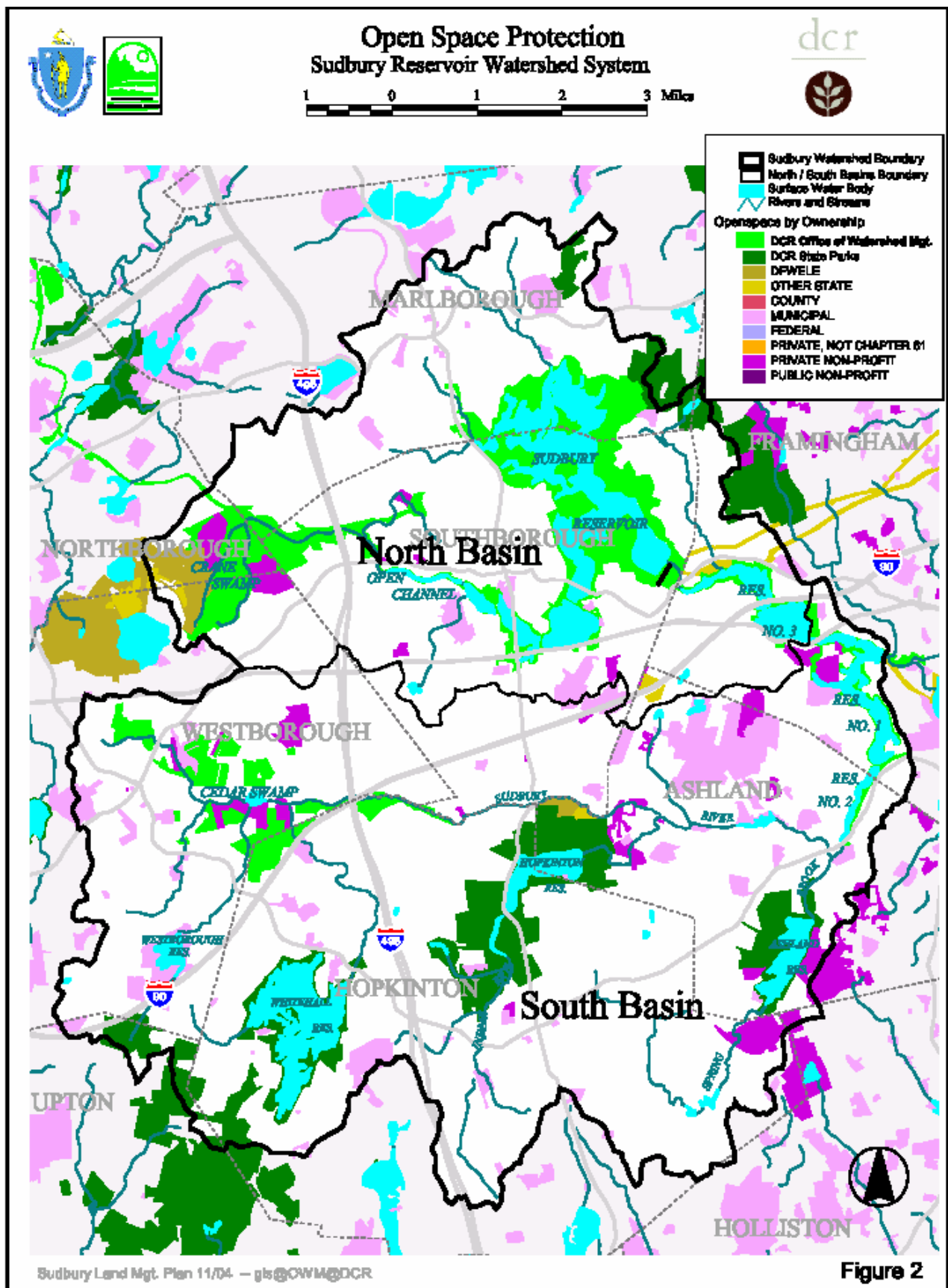


Figure 2: North and South Sudbury Basins



# Land Use / Land Cover Classifications Sudbury Reservoir Watershed System

dcf



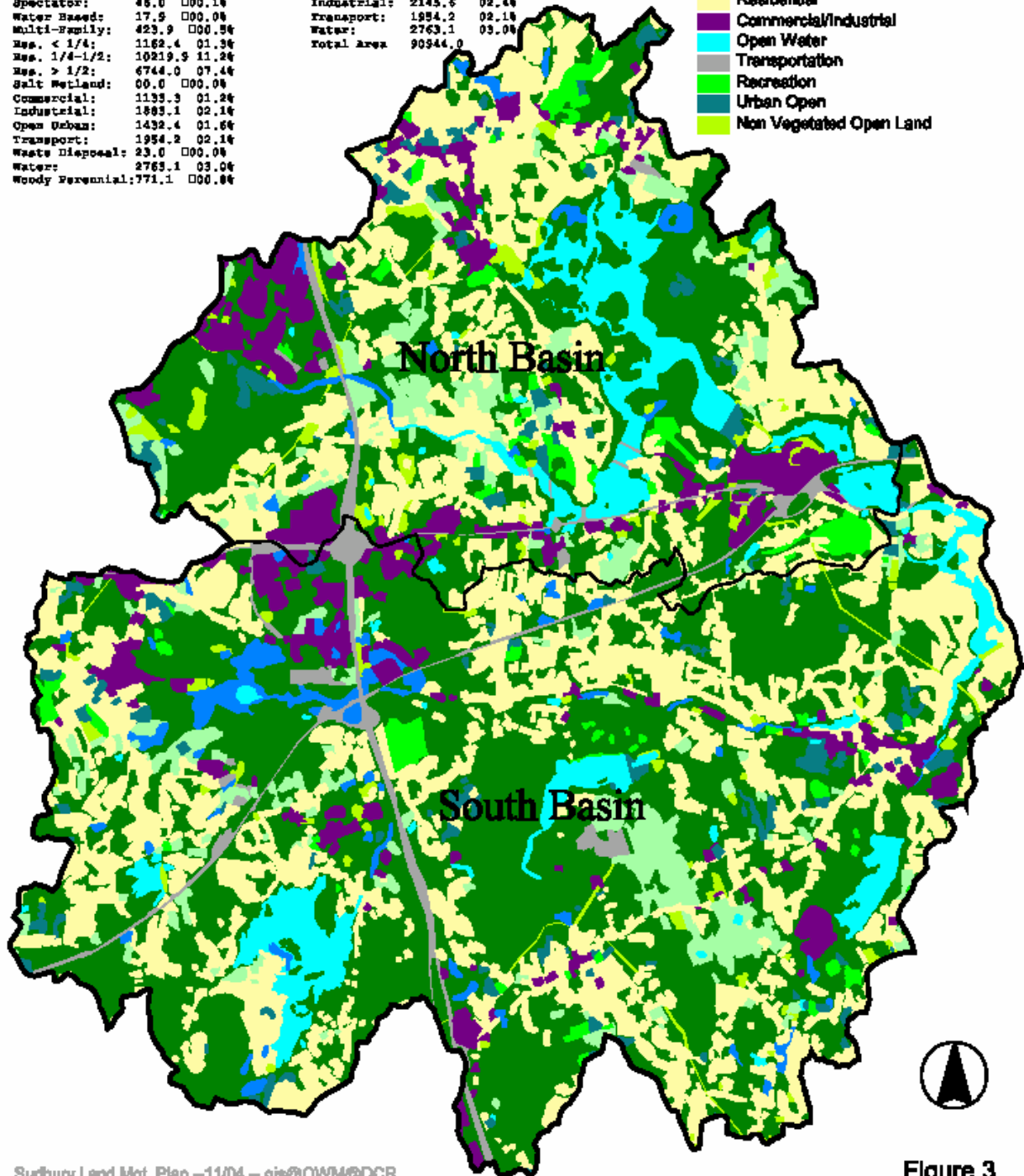
1 0 1 2 3 Miles

## Report of Land Use Statistics In Acres and Percentage of Watershed

Cropland:	1437.3	01.6%
Pasture:	276.2	000.3%
Forest:	57072.0	63.6%
Wetland:	882.7	001.0%
Mining:	239.5	000.3%
Open Land:	822.7	000.9%
Recreation:	830.7	000.9%
Spectator:	48.0	000.1%
Water Based:	17.9	000.0%
Multi-Family:	423.9	000.5%
Res. < 1/4:	1162.4	01.3%
Res. 1/4-1/2:	10219.9	11.2%
Res. > 1/2:	6744.0	07.4%
Salt Wetland:	00.0	000.0%
Commercial:	1135.9	01.2%
Industrial:	1803.1	02.1%
Open Urban:	1432.4	01.6%
Transport:	1954.2	02.1%
Waste Disposal:	23.0	000.0%
Water:	2763.1	03.0%
Woody Perennial:	771.1	000.8%

Land Use Summary:		
Agriculture:	1713.5	01.9%
Forest:	57072.0	63.6%
Wetlands:	882.7	01.0%
Open Land:	3882.7	04.3%
Residential:	18950.1	20.4%
Commercial:	1179.2	01.3%
Industrial:	2145.6	02.4%
Transport:	1954.2	02.1%
Water:	2763.1	03.0%
Total Area:	90344.0	

- Sudbury Watershed Boundary
- North & South Basin Boundary
- Aggregated Land Use / Land Cover Classes**
- Forest
- Wetland
- Agriculture
- Residential
- Commercial/Industrial
- Open Water
- Transportation
- Recreation
- Urban Open
- Non Vegetated Open Land



Sudbury Land Mgt. Plan -11/04 - gis@OWM@DCF

Figure 3

Figure 3: Land Use/Land Cover Sudbury Watershed System

## *Physical Characteristics of Sudbury Watershed Lands*

### **2.3.1 Soils**

For the purposes of watershed management, the Sudbury soils have been grouped and mapped into five classes, based on the most current United States Department of Agriculture Soil Conservation Service publications. These classifications are based upon soil depth and drainage characteristics.

1. **Excessively drained soils:** Excessively drained soils are usually very coarse textured, rocky or shallow. Water is removed from the soil very rapidly. These soils are thick loamy sands occurring primarily on glacial outwash. The principle soils occurring most frequently in these areas are the Hinckley, Merrimac and Windsor series. These are relatively deep soils (>65") and occupy 66% of the area. Inclusions of the Deerfield and Sudbury series occupy the remaining 44% of the area and are located usually in the lower landscape positions. They are moderately well-drained fine sandy loams, usually very deep and very stony.
2. **Well drained thin soils:** These soils are commonly of medium texture. Water is removed from the soil reasonably fast and is available to plants during most of the growing season. The principle soils occurring in these areas are the Chatfield-Hollis-Bedrock complex. This complex consists of 45% deep Chatfield soils, 25% shallow Hollis soils, 5% rock outcrops, and 25% other soils. These other soils, listed as inclusions, are the well drained Canton soils on the lower slopes and very poorly drained Swansea, Freetown and Whitman soils in depressions.
3. **Well drained thick soils:** These thick (24"-65") soils are formed in loamy and sandy glacial till on uplands. The Paxton and Canton series are generally found on the lower sides of hills and ridges. Inclusions are dominated by poorly drained Ridgbury soils and very poorly drained Whitman and Swansea in swales and low lying areas.
4. **Moderately well drained soils:** Moderately well drained soils are wet for only a short period during the growing season but the removal of water is somewhat slow during these times. These soils consist of very deep, (to 65" and greater) fine sandy loams. The Sudbury and Deerfield series are formed on outwash plains and terraces and occupy nearly level positions on the landscape. Other soil inclusions found within these types have been identified as the Merrimac, Walpole, Scarboro, Hinckley, and Windsor series. The Woodbridge series are formed on glacial till on uplands and are generally found on the tops of upper parts of hills and ridges. Inclusions of Charlton, Paxton, Canton, Montauk, and Ridgbury may occur within the Woodbridge series. The Scituate soil series, formed in glacial till on the uplands, is commonly found on the lower slopes of hills and ridges. Inclusions within this type are the Montauk, Canton, Woodbridge, Paxton, Ridgbury, and Walpole.
5. **Poorly to very poorly drained soils:** Poor drainage usually results from a high water table where water is removed so slowly that the soil is saturated or remains wet for long periods during the growing season. These soils are very deep, extending to a depth of 50" or more, and consist of fine sandy loams and mucks. The Ridgbury and Whitman series are found in depressions and in low areas on uplands. Inclusions of Woodbridge, Paxton, Scituate, and Swansea series comprise about 20% of these soils. Freetown and Swansea mucks are organic soils formed in depressions and on plain areas. These types can also contain 20% included soils such as the Whitman, Scarboro, Ridgbury, and Walpole series. The Scarboro-Rippowam complex and the Walpole series occur in depressions and along drainage ways. The complex includes 40% Scarboro, 30%

Rippowam, and 30% other soils, while the Walpole has 20% included soils from the Sudbury, Deerfield, and Swansea series.

Note: Because of the scale used in mapping, small areas generally less than 5 acres cannot be shown separately on the soil maps. These small areas are known as inclusions. Urban land and Udorthents (areas altered by excavation and/or filling) are mapped separately and include power transmission lines, administrative areas and filter beds.

TABLE 2: ACRES OF COMPOSITE SOIL TYPE ON OWM SUDBURY PROPERTIES

Types:

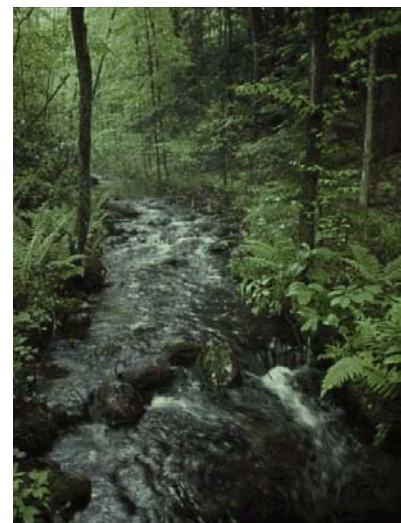
- |                               |   |
|-------------------------------|---|
| 1 = Excessively drained soils | 4 = Moderately well-drained soils       |
| 2 = Well-drained thin soils   | 5 = Poorly to very poorly drained soils |
| 3 = Well-drained thick soils  |   |

	Composite Soil Type				
	1	2	3	4	5
ACREAGE	245	121	685	203	991
PERCENT	11%	5%	31%	9%	44%

Generally, the soil within the Sudbury watersheds supports a wide variety of native tree species, most notably eastern white pine, northern red oak, red maple, black oak, white oak, and white ash. The dominant forest cover is white pine established in plantations during the early part of the 20th century. There are significant red pine plantations as well. Oaks are common on the drier hillsides and red maple dominates the wetter sites. Sugar maple and white ash are generally limited to "sweet" soils (less acidic) with moderately high moisture content. OWM's efforts to create a low-maintenance watershed forest require consideration of site/species compatibility. The 44% of OWM land which has poorly drained soils represent a significant constraint on forestry activity, due to the potential for damage to fragile, organic soils.

### 2.3.2 Hydrology

A land area of 12,457 acres drains into the Sudbury Reservoir and Framingham Reservoir No.3. In order of the estimated volume of inflow to the reservoirs, the most important sub-watershed drainages are Sudbury Reservoir direct inflow (12.6% of total inflow to the reservoirs), Crane Brook (11.2%), Marlborough Brook (North and South) (7.7%), Capen/Hessell/Willow Brooks (7.2%), Angelica Brook (6.4%), Mowry Brook (5.4%), Brewer Brook (5.4%), Hyde/Howe Brooks (5.3%), and Broad Meadow Brook (4.3%) (MWRA/MDC, 1997). Within the portion of the watershed owned by the OWM, there are approximately 3.8 miles of streams, excluding intermittent streams, and 899 acres of wetlands (403 acres in the South Basin and 496 in the North Basin), excluding areas of open water (MDC GIS from 1994 aerial photo interpretation, which may miss some wetland areas, especially under conifer cover).



Annual precipitation since 1898 has averaged 44 inches per year, with a range from 30.1 inches in 1965 to 59.5 inches in 1954. Historically (1898-1995), November has been the wettest month, with an average of 4.11 and a maximum of 8.9 inches of precipitation, while May has been the driest month, with an average of 3.11 inches. The highest precipitation in a single month occurred in August of 1955 when 19.39 inches fell. The average precipitation yield to the Reservoir from the entire watershed is approximately 50%. The storage capacities of the Sudbury Reservoir and Framingham Reservoir No.3 are 7.25 and .5 billion gallons respectively.

The hydrology of the few remaining heavily forested stream drainages within the watershed is strongly affected by the forest cover. Forest cover has both positive and negative effects on water yield, with net yield the result of precipitation, evapotranspiration, interception, soil moisture, and ground water storage. Evapotranspiration losses from forests are significant, with watershed studies showing significant, but highly variable, water yield increases occurring when part or all of a forest cover is removed or replaced by herbaceous vegetation. The most significant yield differences among forest covers are between conifers and deciduous trees. (Note that the current forest cover on OWM Sudbury land is approximately 41% deciduous and 59% conifer, primarily pine.) In general, interception (due to evaporation) and evapotranspirational losses are greater for conifers than for deciduous species, although this varies with stocking and with storm size (deciduous forests average 13% overall interception losses, while coniferous forests average 28% (Dunne and Leopold, 1978)). The creation and maintenance of open land generally reduces this interception loss and can result in a significant increase in yield, although this conversion can also compromise water quality.

The manipulation of forest cover also affects infiltration, storage, and overland flow. While the actual operating model in any given forest is complex, two factors related to forest manipulations have significant effects - organic matter content and pore space. New England forest soils generally absorb water readily, as the accumulation of organic matter plus the burrowing activities of soil organisms create a forest floor with rapid infiltration rates and a large potential water storage capacity. The actual depth of the organic layer is influenced directly by species composition and stocking, with the greatest accumulations occurring beneath dense stands of conifers, where cool, acid conditions delay the decay of organics. While there are differences between species in root depths, tree roots generally function to penetrate deeply into soils, ultimately creating macropores and increasing water storage capacities within and beneath the organic layers of the soil. The maintenance of a forest cover prevents the sharp rises in soil temperature which can cause the rapid depletion of organic matter and thus reduce the water storage and filtering capacity of the forest. Therefore, the replacement of trees with herbaceous cover may reduce water storage.

### **2.3.3 Topography**

The topography of the OWM land in the Sudbury watersheds varies from level to moderately sloped. Steep slopes are few and limited in extent. For the entire Sudbury Watershed (North and South Basins), 97% of the land is 20% slope or less; 74% is 10% or less; only 0.5% is greater than 30% slope. Elevation ranges from 252 feet (elevation of full reservoir) to 464 feet at Pine Hill. The watershed contains numerous drumlins. Walnut Hill is a prime example. Upland slopes are generally covered with glacial till material while lowlands are typically filled with the stratified silt, sand and gravel that constitute glacial outwash. Extensive forested wetlands exist at the north end of the reservoir and in the watershed headwaters at Crane Swamp.

The OWM land in the South Sudbury basin consists mainly of a narrow buffer around the Brackett and Stearns Reservoirs as well as extensive wetlands in the Cedar Swamp. Limited areas of steep slopes occur along portions of the banks of the two reservoirs.

### **2.3.4 Developed Areas**

There are numerous structures and facilities within OWM land that include: MWRA lab and maintenance facilities at the Sudbury Dam and an OWM residence on Salem End Road. Additional facilities include pump stations, the Marlborough filter beds, aqueduct terminal chambers and headhouses, causeways, gatehouses, dams, and spillways. There are 10 miles of unpaved access roads that are maintained by the OWM that occupy approximately 12 acres. Cleared utility rights of way cover roughly 22 acres.

### **2.3.5 Other Open Lands**

Other open lands consist of non-wooded wetlands (212 acres) and mowed lawn areas associated with dams and buildings and other open areas (approximately 339 acres) (OWM GIS from 1992 aerial photography). Areas where forest cover is recovering after storm damage or forestry operations are considered part of the forest cover.

## **2.4 Sudbury Forest and Wildlife Conditions**

### **2.4.1 Forest**

#### **2.4.1.1 Forest Types and Ages**



The current Sudbury forest consists of numerous stands, each defined as "a contiguous group of trees sufficiently uniform in species composition, arrangement of age-classes, and condition to be a distinguishable unit" (Smith, 1986). The simplest Sudbury stands are even-aged conifer plantations of a single species. Complex stands are multi-aged, with a stratified mixture of both shade-tolerant and shade-intolerant species. With the passage of time, stand boundaries which were created and maintained by past land-use practices will fade and stand definition will become less important. However, boundaries between forest types will remain evident where there are significant differences in site characteristics, and these type changes will dictate some differences in management (for instance opening sizes and choices of species where underplanting is required).

Acres of forest types currently under management (Table 3) were obtained from MDC/DWM forest type maps that were created from 1989 to 1994. The most recent version of these type maps has been updated and digitized for use in GIS analysis and mapping. The OWM plans to continually update typing to account for changes. Note that this typing only includes actively managed forest in the North Basin.

TABLE 3: ACREAGE OF MANAGED OWM FOREST ON NORTH BASIN WATERSHED BY TYPE

<i>Type</i>	<i>Acres</i>	<i>Percent</i>
White pine	327	24
Red maple/Mixed hardwoods	313	23
White pine-oak/hardwoods	299	22
Oak	249	19
Mixed pine/Mixed pine-oak/Hemlock	59	5
Red pine	55	4
Spruce	31	2
Others	13	1
TOTAL	1,347	100

TABLE 4: ACREAGE OF MANAGED OWM FOREST ON NORTH BASIN WATERSHED BY SIZE CLASS

<i>Size Class</i>	<i>Acres</i>	<i>Percent</i>
Less than 20 feet tall	100	7
20 to 40 feet	112	8
40 to 60 feet	77	6
60 to 80 feet	768	57
More than 80 feet	290	22
TOTAL	1,347	100

The current Sudbury forest originates primarily from plantation establishment from 1907 to 1947. Of the approximately 1.75 million seedlings planted during this period, the majority were planted from 1913 to 1921. The balance of the Sudbury forest is the result of farm abandonment following the takings of the land prior to reservoir construction. The majority of the managed Sudbury forest is therefore 75+ years old.

There have been 30 silvicultural operations completed on OWM property in the watershed from 1984 through 2003. Salvage operations account for 8 of these operations and occurred on 49 acres. These operations were performed to cleanup damaged trees following Hurricanes Gloria and Bob and dead and dying trees resulting from gypsy moth defoliation and subsequent diseases. The remaining 22 silvicultural operations occurred on 556 acres and included thinnings, removal of diseased and declining plantation overstory trees, and regeneration cuts of varying size to encourage tree regeneration and forest diversity.

#### **2.4.1.2 Forest Inventory**

In 1986 and 1989, trees were measured and information was gathered on 305 variable radius plots throughout Division lands on the Sudbury watersheds, accomplishing the first forest inventory of these lands. All trees from 4" in diameter at breast height and up were tallied. For each tree, the species, diameter, crown classification, product rating (e.g., sawlog, fuelwood, or pulpwood) and desirability rating (an estimate of vigor and form) were collected.

### *Species Distribution*

A random plot inventory clearly showed the predominance of white pine in the managed forest in terms of total basal area (a measure of stocking density based upon tree diameter) (Table 5). The softwood species combined account for 68% of the total basal area.

TABLE 5: DISTRIBUTION OF BASAL AREA BY SPECIES

<i>Species</i>	<i>Percent</i>
White pine	53
Maples	12
Oaks	12
Red Pine	12
Ash	5
Spruce	2
Hickory	1
Others	3

### *Size Distribution*

The distribution of size classes across the Sudbury forest is a useful indicator of structural diversity even though it may be a fairly poor indicator of age structure. The three conventional size classes chosen are: sapling/pole (5.6" to 9.5" dbh), small sawlog (9.6' to 15.5" dbh) and large sawlog (15.6" dbh and up). The total number of trees and the percent of the total number of trees and total basal area are shown in Table 6.

TABLE 6: SIZE DISTRIBUTION OF TREES

<i>Size Class</i>	<i># of Trees</i>	<i>% of Total #</i>	<i>% of Total BA</i>
< 9.6" dbh	95,113	42	16
9.6 - 15.5" dbh	103,591	46	52
> 15.5" dbh	28,566	13	33

Approximately 85% of the total stocking occurs in diameter classes greater than 9.6" dbh. Silvicultural activities have focused on softwood removals. White pine accounts for 71% of the stocking removed from 1987 to 1996. All softwood species combined account for 91% of the stocking removed (Table 7).

TABLE 7: SILVICULTURAL REMOVALS BY SPECIES AND BASAL AREA

<i>Species</i>	<i>1990 BA (sqft)</i>	<i>Cut (1987–1996)</i>	<i>% Cut</i>
White pine	85,863	21,263	24.6
Red pine	19,161	5,091	26.6
Spruce	4,081	1,008	24.7
Oaks	19,824	1,805	9.1
Red maple	19,110	286	1.5
Aspens	321	151	47.2
Others	12,067	359	3.0
TOTALS	160,421	29,864	18.6

### *Growth*

Average annual diameter growth by species was measured using increment cores collected during the summer and fall of 1994 and is summarized in the table below.

TABLE 8: AVERAGE ANNUAL DIAMETER GROWTH BY SPECIES

<i>Species</i>	<i>Growth</i>
White pine (planted)	0.13"/year
White pine (natural)	0.20
Red pine (planted)	0.08
Scotch pine (planted)	0.09
Pitch pine	0.09
Spruce	0.12
Hemlock	0.15
Red oak	0.13
Black oak	0.10
White oak	0.09
Black cherry	0.15
Red maple	0.15
Sugar maple	0.19
Hickory	0.09
White ash	0.16
Aspen	0.18
Black birch	0.11
Paper birch	0.07
American elm	0.20

The difference in growth between plantation white pine and non-plantation white pine is directly attributable to the greater density of trees in the plantations. This high density of stems results in more intense competition between trees, less differentiation among individuals and therefore below optimum growth rates. Had these stands been thinned at some stage in their development, their growth rates would be comparable to the non-plantation rate. Indeed, many of the non-plantation stands originated as white pine plantations but were infiltrated by opportunistic hardwood species.

#### **2.4.1.3 Regeneration Conditions**

Regeneration serves to anchor soils following disturbances, resist damage from many disturbances (due to size and density), assimilate nutrients more rapidly than older vegetation, and shorten recovery times for reestablishing forests following disturbances. For these reasons, the ability of the watershed forest to regenerate continuously in the face of a wide variety of disturbances is considered critical to its ability to protect water quality.

Regeneration is most noticeably lacking under untreated plantations on the Sudbury watersheds. The limiting factor under these stands is the low light levels reaching the forest floor due to the dense

canopy. Closed plantations that have significant regeneration present are often adjacent to large roadside sugar maple trees. Sugar maple is highly tolerant of low light situations and is able to build up a reservoir of regeneration over a period of years. Openings that are created in the overstory by storm events or silviculture also trigger a regeneration response. The increased light both in the opening itself and in the adjacent plantation allows a wider range of species to become established.

Many of the oak stands are limited in their levels of regeneration of either oak or associated species. Oak is among the more valuable species in the watershed forest, as a long-lived, low-maintenance species with high wildlife and timber values. However, oak is problematic to regenerate on many sites, and historically thrived best following intensive harvesting and fires that reduced competition from other species. Oak regeneration is particularly lacking beneath dry-site stands. Huckleberry and bracken and hay-scented ferns are often inhibiting influences. Mortality of the oak overstory initiated by gypsy moth defoliation often has a beneficial effect on general regeneration establishment, due to increases in light and short-term increases in nutrient availability. However, large scale mortality of overstory oak also further reduces the likelihood of regenerating oak.

Overall, there is good regeneration in many areas of the Sudbury forest currently and excellent potential for establishing regeneration where it is lacking. No statistical sample of the regeneration over the entire forest has been completed to date. OWM foresters have determined the level of regeneration at Walnut Hill resulting from the silvicultural operation in 1987-88 and storm salvage in 1989 in this extensive white and red pine plantation (Buzzell, 1993).

Three distinct zones with differing light conditions were defined at Walnut Hill. Zone 1 consists of strip cuts and other openings. Here the regeneration is dominated by cherry (both black and pin) with aspen, red maple, and white pine occurring in lesser amounts. Regeneration of all sizes less than 1 inch diameter at 4.5 feet high averages 9,310 stems per acre. Zone 2 includes unmanaged plantations that are within 100 feet of a strip or other opening and managed plantations that have a residual basal area less than 100 sqft/acre (i.e., stands that have been thinned). The regeneration here averages 8,230 stems per acre and is dominated by white pine with lesser amounts of red maple, oaks, cherries, and white ash. Zone 3 is the unmanaged plantations more than 100 feet from an opening. Here, there are only 1,330 stems per acre with a composition of white ash, oaks and cherry.

Not only is the amount and species composition of regeneration different in these three zones but the height development is distinct as well. Regeneration was grouped into three size classes; seedling (less than 1 foot tall), small sapling (1 foot to 4.5 feet tall), and large sapling (>4.5 feet tall to 1 inch diameter at 4.5 feet) (Table 9).

TABLE 9: WALNUT HILL REGENERATION

<i>Zone</i>	<i>Stems per acre</i>	<i>Seedling</i>	<i>Small sapling</i>	<i>Large sapling</i>
1 (within strip cuts and other openings)	9,310	12% (1,117)	52% (4,841)	36% (3,351)
2 (unmanaged plantation < 100 ft from opening or managed < 100 sq ft BA)	8,230	53% (4,362)	42% (3,457)	5% (411)
3 (unmanaged plantations >100 feet from strips or other openings)	1,330	42% (559)	50% (665)	8% (106)

## **2.4.2 Wildlife**

All species of wildlife depend on the existence and quality of various habitat types. Some species require a very specific habitat to survive (i.e., wood frogs and vernal pools), while other species can exist in a variety of habitats (i.e., coyote). The Sudbury watershed is located in a highly developed area of eastern Massachusetts. Natural lands within the watershed are highly fragmented and separated by residential and industrial development. OWM owned land within the watershed is primarily forested. Although the landscape as a whole is fragmented, OWM owned land within the watershed represents a relatively large area of undisturbed habitat. The undeveloped and unbroken nature of these lands is a tremendous benefit to wildlife species that require large tracts of land.

The Sudbury watershed supports a variety of wildlife. OWM lands provide habitat for a diversity of birds and mammals including white-tailed deer, turkey, raccoons, and foxes. In addition, Neotropical migrant birds, including black and white warblers, rose-breasted grosbeaks, and scarlet tanagers utilize OWM forests for breeding and migratory rest stops. The largest and potentially most important habitats within the Sudbury watersheds are the open waters from the various reservoirs. These reservoirs provide aquatic habitat for migrating and resident waterfowl and other water dependent species. The two large wetlands located within the Sudbury watersheds (Crane Swamp and Cedar Swamp) support additional wetland species. Finally, several vernal pools occur on OWM land and support a unique and dependent host of animals.

One of the most important aspects of OWM land on the Sudbury watersheds is its protection from development. Some towns within the watershed are experiencing tremendous growth, and as a result open space is being converted to residential areas. The protection that OWM lands provide to wildlife species is critical to their long-term survival.

Only a few formal wildlife surveys are conducted on OWM land in the Sudbury watersheds. Common loons are surveyed each summer to document reproduction, and vernal pools are documented and sampled each spring.

While a great deal of information exists about common wildlife taxa (i.e., birds, mammals) through information collected from surveys and observations, very little is known about other Sudbury wildlife. A complete species list does not exist, and there is a paucity of information about reptiles, amphibians, insects, butterflies, dragonflies, and other more secretive species. It is quite possible that OWM lands within the Sudbury watersheds harbor state listed species that have yet to be documented.

## **2.5 Cultural Resources**

### **2.5.1 State of Knowledge**

Archaeological records document the presence of Native American sites throughout the Sudbury drainage. Significantly, these sites span the entire course of human settlement in New England, and reflect prehistoric settlement patterns that developed along the Sudbury, Assabet, and Concord rivers. The confluence of these rivers reveals evidence of particularly extensive human activity. Within the Sudbury Reservoir watershed itself, the Massachusetts Historical Commission (MHC) records fifty prehistoric sites, with thirty-two of these located in and around Cedar Swamp in Westborough. Cedar Swamp is listed on the National Register of Historic Places as an Archaeological District. There are five

prehistoric sites within OWM holdings in the Sudbury Reservoir watershed, three of which are in the Cedar Swamp Archaeological District.

Based on thousands of known sites in Massachusetts, archaeologists have developed a model for making predictions about archaeologically sensitive areas, and to a degree the expected type and range of sites that may be found in any given area. The application of *Site Location Criteria* has become a valuable tool for identifying and thus protecting potentially sensitive locations. When utilized in the Sudbury watersheds it can become basis for managing archaeological resources on OWM lands.

As noted, 50 prehistoric sites are currently recorded within the Sudbury watersheds in general, and only five on OWM's lands. While informative, this figure is artificially low. Although the MHC's records are the single most complete archaeological data bank in the state, they represent but a small fraction of the actual number of sites that are known to avocational archaeologists and collectors. Importantly, because of the protected nature of the watershed lands, many sites have survived the destruction that has occurred elsewhere, and it is these as yet unidentified sites that are a major concern to the OWM management team.

## 2.5.2 Prehistoric Overview

Existing archaeological evidence suggests that *Paleo Indian* hunters and gatherers entered the tundra-like New England landscape 9,500 to 12,000 years ago, and these first colonists reached the Sudbury River drainage at that time. By about 9,500 years ago the warming climate had created an environment in southern New England that supported a mixed pine-hardwood forest. Archaeological sites indicate that human occupation of the drainage continued during the *Early Archaic period* (ca. 9,500 to 8,000 years ago).

During the *Middle Archaic period* (ca. 8,000 - 6,000 years ago) climatic and biotic changes continued and the mixed deciduous forests of southern New England were becoming established. Significantly, the present migratory patterns of many fish and birds are believed to have become established at this time (Dincauze, 1974). During the spring those rivers, streams and ponds utilized by anadromous fish for spawning would have been particularly important for fishing. Groups are likely to have traveled considerable distances to camp adjacent to falls and rapids where they could easily trap and spear the salmon, herring, shad and alewives. This subsistence strategy persisted throughout prehistory. Evidence of Native American occupation of the Sudbury region is well documented during *Middle Archaic* times.

There is a marked increase in site frequencies and densities within the Sudbury drainage during the *Late Archaic period* (ca. 6,000 to 3,000 years ago). This pattern is consistent with findings throughout most of southern New England, and may document a population increase during this period. Each of the three traditions - the Laurentian, Susquehanna and Small Stemmed Traditions - is well represented in the archaeological record of local sites. Terminal Archaic activity (ca. 3,000 - 2,500 years ago) includes a steatite quarry.

During the *Early, Middle and Late Woodland* periods (3,000 - 450 years ago) Native Americans continued to occupy the Sudbury River drainage. Site frequencies are comparable or slightly higher than other drainages in eastern Massachusetts. Regionally, horticulture was introduced during the Early Woodland and small gardens may have been planted in clearings located on the fertile alluvial terraces next to the Sudbury River and its larger tributaries.

Analysis of artifacts from local sites reveals a pattern of multiple, recurrent occupation of well situated sites. Few sites have yielded artifacts from a single cultural/temporal period. Instead, artifacts from several periods have typically been recovered from sites. This suggests that some particularly well-sited locations were occupied, or otherwise utilized, more than once. Recurrent, though intermittent, occupation of a single site, sometimes over a period of several thousand years, appears to have been the prevalent pattern of prehistoric site development in this region.

Small groups, probably based on kinship, would have found the uplands most attractive for short term occupation. Settlement is likely to have occurred on virtually any elevated, level and well-drained surface that was located immediately adjacent to sources of fresh water, including the headwaters of ephemeral streams, springs, and small wetlands and ponds. Rock shelters and other natural overhangs, and locations with southerly exposures would also have been utilized.

### **2.5.3 Historic Sites**

An historic survey of the Metropolitan Water Supply System was conducted in 1983 by the MDC to document historic buildings and structures that were related to the development of the Metropolitan Water System. This was followed by a comprehensive inventory of historic watershed buildings and structures by Berger Associates in 1985, and resulted in a multiple resource nomination to the National Register of Historic Places. The nomination was accepted in January of 1990 as the ***Water Supply System of Metropolitan Boston Thematic Resource Area***.

Included in this listing are eight historic districts, which comprise 73 buildings and structures, and sixteen individual properties. Within the Sudbury watersheds are located the Sudbury Dam Historic District and a number of individual buildings, structures, and sites which are part of other National Register Historic Districts located within the Sudbury system. The National Register status of these properties provides them with an important level of protection, as any modifications to them, and/or their grounds, must follow the ***Secretary of the Interior's Standards for Historic Preservation Projects***, and be reviewed and approved by the MHC.

To date the OWM Sudbury lands have yet to be surveyed for the existence of historic archaeological sites. It is expected that watershed lands contain the remains of an occasional farmstead, with its various buildings, and possibly former mills, and other industrial and commercial sites that were located here before the lands were acquired by the Commonwealth.

While the location of a few sites is known, a comprehensive survey will be required to systematically identify others, and to determine their condition, integrity, and significance. These data will provide that basis for formulating a management strategy for the preservation of historic archaeological resources within the Sudbury watersheds.